CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

This work has shown that remote measurement of aphid-induced stress to estimate aphid density and separate the injured wheat from the healthy one at 0.25 m^2 canopy level in the field conditions was successfully employed.

Results reported in this work indicate feasibility of using remote sensing imageries at large scales to detect and discriminate aphid feeding damage in wheat and possibly in other crops.

We expect to work spectral measurements of interactions between aphid pest and host plants at larger scales using hyperspectral and multidate imageries.

Future work will continue to collect spectral data for aphid infestation on agricultural crops not only in the field conditions but also controlled environment.

Discrimination of three level of stress: water, nutrient, and aphid in wheat and sorghum will be the focus of the work in the near future.

Future work will also concentrate to develop and validate a spectral aphid stress index for major crops.

REFERENCES

Bork, E.W., N.E. West, K.P. Price, and J.W. Walker. 1999. Rangeland cover component quantification using broad (TM) and narrow-band (1.4 NM) spectrometry. J. Range Manage. 52 (2):249-257.

Gemmell, F. and J. Varjo. 1999. Utility of reflectance model inversion versus two spectral indices for estimating biophysical characteristics in boreal forest test site. Remote Sens. Environ. 68:95-111.

Peñuelas, J., R. Isla, I. Filella, and J. L. Araus. 1997. Visible and near-infrared reflectance assessment of salinity effects on Barley. Crop Sci. 37:198-202.

Reidell, W. E. and T. M. Blackmer. Leaf reflectance spectra of cereal aphid-damaged wheat. Crop Sci. 39:1834-1840.

ii. The search for a Distinct Spectral Signature for Greenbug and Russian Wheat Aphid Injured Wheat

Written by Zhiming Yang
Other Participants, Mahesh Rao, Norman Elliott, Dean Kindler, and Kris Giles.

Detection of Greenbug Infestation Using Ground-based Radiometry

Zhiming Yang

Challenges to detection

- Coexistence of water stress and greenbug infestation
- Confusion with infestation by Russian Wheat Aphid
- Timing issues in detection
  - Before greenbug density reaches maximum
  - Thresholds may be different at different growth stages

Principles of Stress Detection By Remote Sensing

- Leaf(canopy)reflectance
  - determined by leaf surface properties, internal structure, the concentration and distribution of biochemical components
  - most important: water and chlorophyll
- Canopy temperature – leaf transpiration

Research objectives

- To identify bands sensitive to greenbug infestation
- To identify vegetation indices sensitive to greenbug infestation
- Differentiating greenbug infestation with water stress and infestation by RWA
- To study impact of plant growth stage

Experiment facilities

Greenhouse and cropscan radiometer system

Sensors

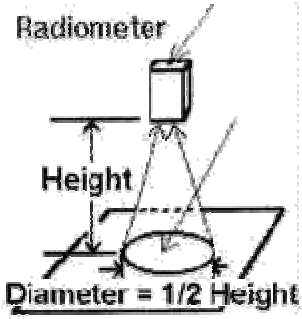
Data logger

CR-1O Weather station

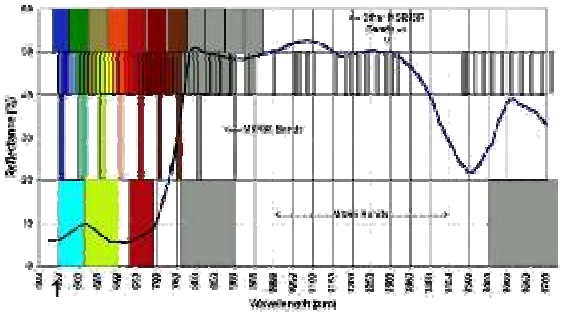
HOBO sensor

Soil moisture sensor

Operation and bands of Cropscan radiometers (MSR16R)



Field of view = 28°



Available bands for MSR16R

Band distribution for the Cropscan radiometer (MSR16R) in this study

Band name		Narrow (± 5nm)	Broad (>± 30nm)
Visible	Blue	1. 450	485
	Green	2. 580	560
	Red	620	660
		630	
		670	
		680	
		694	
		800	
NIR (Near Infrared)		900	830
		950	
MIR (Middle Infrared)		1480	1650

Experiment methods

- Planting:
  (1) Variety - TAM 107

  (2) Seed spacing 1in. x 3 in.
  (3) Plastic flats - 24 in. x 16 in. x 8.75 in (4)
  Soil - Redi-earth
  Plug and Seedling Mix (5)
  Pesticides – Marathon(1% granular)

- Infesting:
  (1) At two leaf stage, 15 days after sowing

  (2) Greenbug (biotype E), wingless adults (3)
  Density: 1 greenbug per plant

Experiment methods cont.

- Data collection
  - Reflectance measurements at nadir angle at noon time daily
  - Temperature and humidity using CR -10 or Hobo temperature and humidity sensor
  - Greenbug density (count GB on 10 plants and get average every three days)
- Plant Management
  - Fertilized once two weeks;
  - Watered 1-2 times a week.

Experiments conducted in this study

Treatments	Experiment Name	Sym-bol	Purpose	Time Periods
greenbug-infested without pesticide	Sensitivity experiment 1	SEex 1	Test sensitivities of band	Jan16 - Mar 12, 2002
non-infested with pesticide	Sensitivity experiment 2	SEex 2	and vegetation indices	Mar16 – May 1, 2002
control (non-infested without pesticide)	Sensitivity experiment 3	SEex 3		Nov 11 – Dec 24, 2003
greenbug-infested without water stress (NW+I)	Differentiating experiment 1	DIex 1	Differentiate greenbug infestation	Nov 5 – Dec 8, 2002
non-infested with water stress (W+NI)	Differentiating experiment 2	DIex 2	and water stress	Mar17 – Apr 13, 2003
control (non-infested without water stress) (NW+NI)	Differentiating experiment 3	DIex 3		Nov 11 – Dec 24, 2003
infested and water stress (W+I).				

Experiments conducted in this study (continued)

Treatments	Experiment Name	Sym-bol	Purpose	Time Periods
greenbug-infested at two-leaf stage greenbug-infested at tillering stage control (non-infested) at two-leaf stage control (non-infested) at tillering stage	Stage experiment	STex	Test impact of growth stage	Jan 18 – Feb 26, 2003
greenbug-infested Russian Wheat Aphid - infested control (non-infested)	GB and RWA experiment	GRex	Compare two kinds of infestations	Oct 30 – Nov 20, 2003

Data Processing and Analysis

- SAS program for repeated measures –
  PROC MIXED, PROC GLM

- Threshold Day and Maximum Day
  Threshold Day
  - the day subsequent to which there is always a significant difference between treatments;

  Maximum Day -
  the day at which greenbug density reaches maximum

- Correlation analysis –
  Correlation coefficients: differences in reflectance/vegetation indices vs. GB density
  – Significance test for correlation (p=0.05)

Data Processing and Analysis

- Sensitivity analysis (band and indices)

  $Sensitivity_{band} = (Ref_{inf} – Ref_{ctrl})*100 / Ref_{ctrl}$, where

  $Sensitivity_{band}$ – Sensitivity for a given band

  Ref_{inf} – Canopy reflectance of infested plants;

  Ref_{ctrl} – Canopy reflectance of control plants.

- Differentiating water stress and greenbug infestation: - Compare Threshold Day and Maximum Day

- Impact of growth stage on sensitivity of band or VI - Testing correlation and relative sensitivities

- Compare two kinds of infestations
  - Compare Threshold Day and Maximum Day

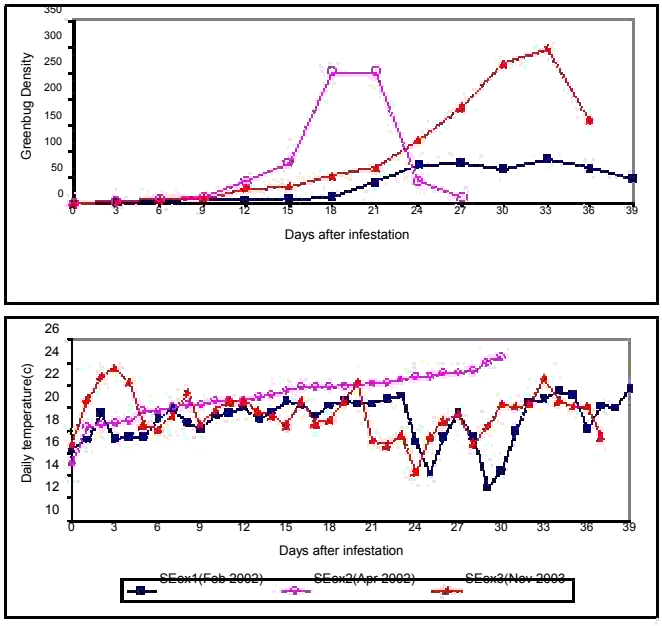
Vegetation indices used in various studies

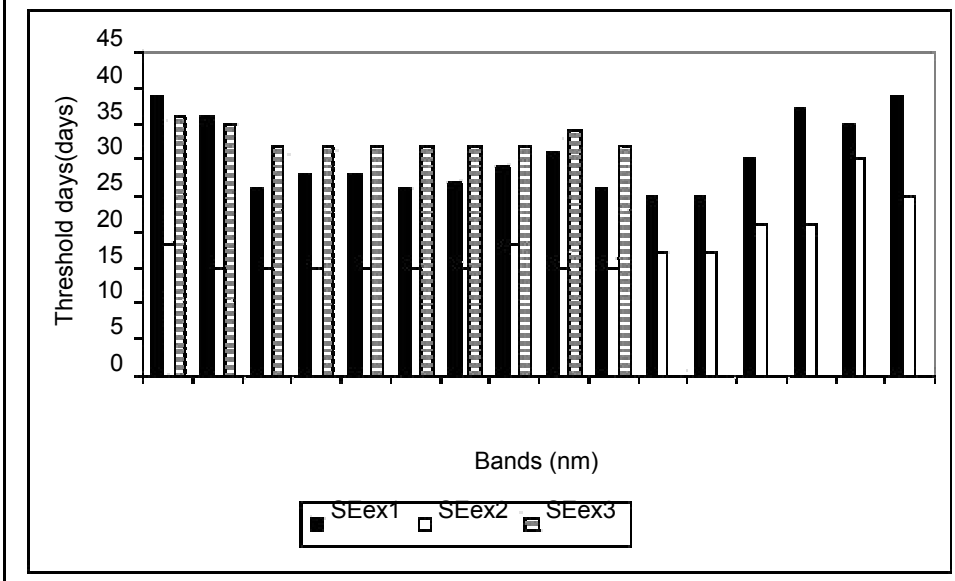
Vegetation Index	Formula
Atmospheric Resistant Vegetation Index, ARVI (Kaufman and Tanre, 1996)	**ARVI = (NIR – (2red – blue))/(NIR + (2red – blue))**
Difference Vegetation Index, DVI (Tucker, 1979)	**DVI=NIR-Red**
Enhanced Vegetation Index, EVI (Verstraete and Pinty, 1996)	**EVI=(1+L) (NIR-red)/(NIR+C1*red - C2*blue+L) C1=6.0, C2=7.5, L=1.0**
Global Environmental Monitoring Index, GEMI (Pinty and Verstraete, 1992)	**GEMI=?(1-0.25?)-(red - 0.125)/(1-red)** **| =[2(NIR^2-red^2)+1.5NIR-0.5red] /(NIR+red+0.5)**
Modified Soil Adjusted Vegetation Index Two, MSAVI2 (Qi et al., 1994)	**MSAVI2 =1/2 * [(2*(NIR+1)) - (((2*NIR)+1)^2 – 8 (NIR-red))$^{1/2}$]**
Optimized Soil Adjusted Vegetation Index, OSAVI (Rondeaux et al., 1996)	**OSAVI = ((NIR-red)/(NIR+red+L))*(1+L); L=0.16**
Normalized Difference Vegetation Index, NDVI (Rouse et al., 1973)	**NDVI=(band1-band2)/(band1+band2)**

Vegetation indices used in various studies (continued)

Vegetation Index	Formula
Normalized total Pigment to Chlorophyll Index, NPCI (Riedell and Blackmer, 1999)	NPCI = (R680-R430) / (R680+R430))
Ratio Vegetation Index, RVI (Jordan, 1969)	RVI=band1/band2
Soil-Adjusted Vegetation Index, SAVI (Huete, 1988)	SAVI = (1+L)* (band1-band2) /(band1+band2+L); L=0.5
Structural Independent Pigment Index, SIPI (Penuelas and Inoue, 1999)	SIPI=(R800-R450)(R800-R680)
Specific Leaf Area Vegetation Index, SLAVI (Lymburner et al., 2000)	SLAVI=NIR/ (Red + MIR)
Vegetation Index One, VI1 (Viña, 2002)	VI1=NIR/green -1
Vegetation Index Two, VI2 (Viña, 2002	VI2= R800/R694 -1
Yellowness Index, YI (Adams et al., 1999)	YI=(R580 – 2R630+R680)/?^{2}, ?=50 nm
Water Band Index, WBI (Riedell and Blackmer, 1999)	WBI=R950/R900

Temporal changes in greenbug densities and daily temperatures





Maximum Days: 33(SEex1), 21(SEex2), 33(SEex3)

Correlation Coefficients and sensitivities of bands

Band (nm)	Correlation coefficient			Difference (%)#			
	SEex1	SEex2	SEex3	SEex1	SEex2	SEex3	Average
BAND560	0.7924*	0.9647*	0.9211*	20.29	36.49	31.68	29.49
BAND580	0.7104*	0.9632*	0.9310*	20.12	46.35	39.8	35.42
BAND620	0.6785*	0.9122*	0.8800*	21.76	67.42	28.76	39.31
BAND630	**0.7318***	**0.9459***	**0.8877***	**23.88**	**66.43**	**34.3**	**41.54**
BAND660	0.7701*	0.9039*	0.8741*	20.56	62.59	28.71	37.29
BAND670	0.6924*	0.9592*	0.9066*	17.65	55.09	32.29	35.01
BAND680	0.7804*	0.9480*	0.8373*	20.42	66.92	17.34	34.89
BAND694	**0.8288***	**0.9093***	**0.8992***	**22.85**	**73.79**	**30.31**	**42.32**
BAND800	-0.7271*	-0.9255*	0.1552[?]	-6.32	-19.59	-12.47	-12.79
BAND830	-0.7099*	-0.9313*	0.2272[?]	-5.27	-17.07	-9.49	-10.61

*: significant at 0.05 level; ?: not significant
#: Difference in reflectance between infested and control plants at Maximum Day

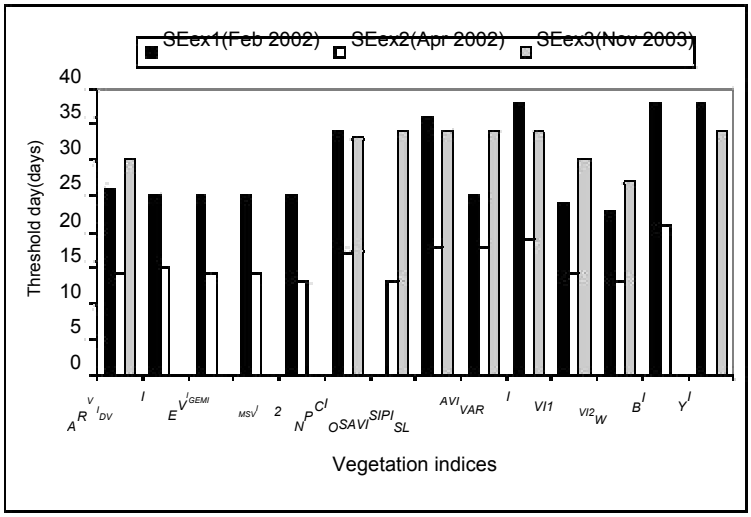
Most sensitive

Correlation Coefficients and sensitivities of selected VI

vegetation indices	correlation coefficients*		
	SEex1	SEex2	SEex3
NDVI_830_560	-0.7208	-0.9471	-0.8929
RVI_800_620	-0.7761	-0.96	-0.9511
RVI_800_630	-0.8089	-0.977	-0.9421
RVI_800_670	-0.7849	-0.9615	-0.9413
RVI_800_680	-0.8371	-0.9652	-0.9176
RVI_800_694	-0.8536	-0.9404	-0.9547
RVI_830_485	-0.7524	-0.9698	-0.8961
RVI_830_660	-0.8492	-0.9326	-0.9458
RVI_900_450	-0.8033	-0.9382	-0.7377
RVI_900_580	-0.7937	-0.9524	-0.8129
RVI_900_620	-0.7682	-0.9626	-0.8655
RVI_900_630	-0.8092	-0.9808	-0.8496
RVI_900_680	-0.8421	-0.967	-0.8438

Most sensitive

Threshold Days of Special Vegetation indices



Maximum Days: 33(SEex1), 21(SEex2), 33(SEex3)

Correlation Coefficients and sensitivities of some special vegetation indices

Vegetation Indices	Correlation coefficient			Difference (%) #			
	SEex1	SEex2	SEex3	SEex1	SEex2	SEex3	Average
EVI=(1+L) (NIR-red)/(NIR+C1* red - C2*blue+L)	-0.4520	-0.7591*	-0.4075	-8.28	-34.15	-22.51	-21.65
ARVI = (NIR – (2red – blue))/(NIR + (2red – blue))	0.1541	-0.7152*	-0.8749*	-9.09	-40.35	-27.87	-25.77
MSAVI2 =1/2 * [(2*(NIR+1)) - (((2*NIR)+1)^2 – 8 (NIR-red))$^{1/2}$]	-0.7377*	-0.9140*	-0.6319*	-5.50	-18.39	-9.09	-10.99
GEMI=?(1-0.25?)- (red - 0.125)/(1- red) | =[2(NIR^2-red^2)+1.5NIR-0.5red] /(NIR+red+0.5)	-0.6088*	-0.9042*	-0.1881	-4.71	-18.42	-9.56	-10.90
DVI=NIR-Red	-0.5799	-0.9140*	-0.1757	-9.14	-33.14	-19.53	-20.61

Sensitive bands and vegetation indices

Band(nm)	Ranking	Vegetation indices	Ranking	Vegetation indices	Ranking
694	1	VI2_ 800_694	1	RVI_900_580	14
630	2	VI1_830_560	2	RVI_900_670	15
620	3	RVI_800_694	3	RVI_950_620	16
660	4	RVI_800_630	4	RVI_900_680	17
580	5	RVI_900_694	5	RVI_950_580	18
670	6	RVI_800_620	6	RVI_950_670	19
680	7	RVI_900_630	7	RVI_830_560	20
560	8	RVI_950_694	8	RVI_950_680	21
		RVI_800_670	9	RVI_830_485	22
		RVI_900_620	10	RVI_800_450	23
		RVI_830_660	11	RVI_900_450	24
		RVI_950_630	12	NDVI_830_560	25
		RVI_800_680	13	RVI_950_450	26
				MSAVI2	27

Most sensitive

Differentiating greenbug infestation and water stress

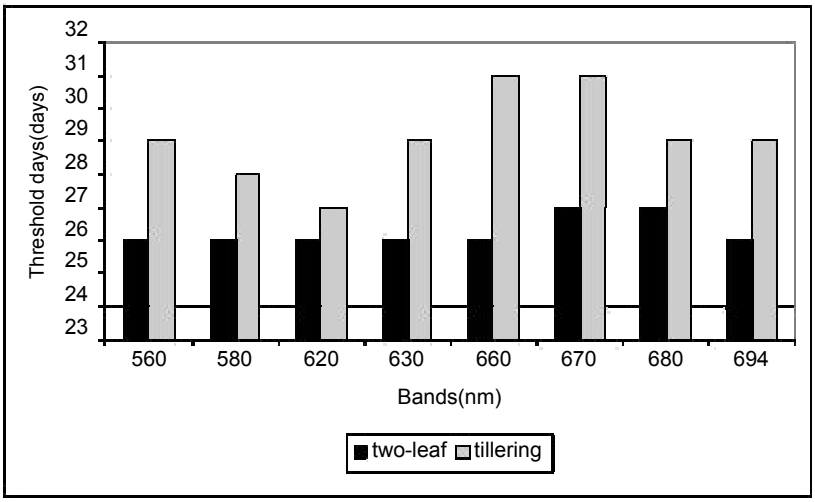
	Threshold Days		
Band (nm)	DIex1(Nov 2002)	DIex2(Mar 2003)	DIex3(Nov 2003)
560	no	27	28
580	no	24	31
620	34	27	32
630	34	27	32
660	32	27	34
670	32	27	36
680	34	27	35
694	34	27	34
Maximum Day	18	21	33

Note: there are no Threshold Days

Threshold Days of Selected VI used to differentiate water stress from infestation

Vegetation indices	DIex1(Nov 2002)	DIex2(Mar 2003)	DIex3(Nov 2003)
NDVI_830_560	17	27	31
RVI_800_450	no	25	31
RVI_800_694	18	22	28
RVI_830_485	30	25	33
RVI_830_660	18	22	29
RVI_900_620	17	27	28
RVI_900_630	18	27	28
RVI_900_680	17	24	28
RVI_900_694	18	21	28
RVI_950_670	21	27	28
RVI_950_680	20	24	28
RVI_950_694	18	21	28
VI1_830_560	17	26	31
VI2_800_694	18	22	28
MSAVI2	21	28	no
Maximum Day	18	21	33

Impact of stage on detection for bands



Comparing aphid infestations

Band(nm)	GB-Control	RWA-Control	GB-RWA
560	14	13	no
580	14	13	no
620	15	13	no
630	15	13	no
660	17	9	no
670	17	13	no
680	17	13	no
694	15	13	no
Maximum Day	18	18	

note: there are no Threshold Days
GB-Control: comparison between plants infested by GB and control plants;
RWA-Control: comparison between plants infested by RWA and control plants; GB-RWA: comparison between plants infested by GB and plants infested by RWA;

Threshold Days of Select VI Used to compare two kinds of infestations

Vegetation indices	GB-Control	RWA-Control	GB-RWA
RVI_800_450	18	9	9
RVI_800_620	15	9	no
RVI_800_694	16	9	20
RVI_900_670	16	11	20
RVI_900_680	16	9	20
RVI_900_694	15	11	19
RVI_950_450	18	9	9
RVI_950_580	14	9	19
RVI_950_620	14	9	20
RVI_950_630	15	9	19
RVI_950_694	15	9	19
VI1	14	9	no
VI2	16	9	20
MSAVI2	16	9	no
NPCI	16	no	16
YI	17	no	14

Sensitive bands

Band (nm)	Differentiate W and I	Stage impact	Differentiate G & R	Sensitive bands(?)
694	v	#	x	*
630	v	#	x	*
620	v	#	x	*
660	v	#	x	*
580	x		x	
670	v		x	
680	v	#	x	*
560	x		x	

W: water stress, I: Infestation, G: greenbug infestation, R: infestation by RWA
v: can be used, x: cannot be used, : #: can be used at both stages, *:sensitive band

Conclusions

- Sensitive bands:
  (Visible Red) 620, 630, 660(broad), 680, 694 nm
- Sensitive vegetation indices:
  VI2_800_694, RVI_800_694, RVI_950_694, RVI_950_620, RVI_900_680, RVI_950_680
- Landsat TM bands and derived vegetation indices such as VI1_830_560 could be used to detect aphid infestation.
- It is possible to detect greenbug infestation using sensitive bands or vegetation indices determined in this study.

Future research needs

- Hyper-spectral study using ASD spectrometer (350-2500 nm) at 2 nm resolution
- Differentiate greenbug infestation with nutrient deficiency and plant diseases
- Field studies to test sensitive bands and vegetation indices
- Investigate the unique spatial patterns caused by greenbug infestation
- Developed detection method by remote sensing to an effective decision tool for farmers